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THE SPITZ PLANETARIUM, McMASTER UNIVERSITY, HAMILTON, ONTARIO*

By William J. McCallion and Truman M. Norton
Hamilton Centre

The presentation of a Spitz Planetarium by the members of the Hamilton Centre, R.A.S.C., to McMaster University on November 5, 1949 was an important occasion in the history of the Centre. This instrument was the first of its kind to be installed in Canada and the third one to be sent outside the United States.

The story behind this presentation goes back to April 24, 1949, when a similar planetarium was formally opened at the Buffalo Museum of Science in Buffalo, N.Y. Geo. E. Campbell, M.A., a past president of the Centre, had seen the instrument a few days previously and was impressed by its versatility and low cost. Several members of our executive visited the museum, saw a demonstration of the planetarium and through the courtesy of Mr. Ellsworth Jaegar, Curator of Education for the Museum, arranged a meeting with Mr. Armand Spitz, who was present for the occasion. As a result of this meeting with Mr. Spitz, we returned home convinced that Hamilton needed a planetarium.

A council meeting was held immediately to discuss the possibility of having a planetarium in this city. In the meantime, McMaster University had been approached through Dr. A. E. Johns and Professor W. J. McCallion of the Mathematics Department, who were also valued members of the Council. As a result the University offered to provide suitable housing for a permanent installation and to build the dome at its own expense. In the minutes of a council meeting on May 27th there

*A summary of this article was presented at the session for papers at the Annual Meeting, March 14, 1959.

is recorded a motion by Mr. Geo. E. Campbell, seconded by Mr. W. D. Stewart that the Hamilton Centre, R.A.S.C., purchase a Spitz Planetarium and present it to McMaster University, to be used jointly by the University and the Society. This motion was carried unanimously.

The question of financing became of prime importance. The Hamilton Centre which was a small centre of about 50 members was struggling to get back on its feet after the war. The cost of the projector and attachments would be in the neighbourhood of $1,000. The adverse rate of exchange prevailing at the time, however, would increase the actual cost to $1,150. Thus an ambitious programme was launched for the members of the Hamilton Centre.

The project was first made public at the annual Field Night on Friday evening, June 3, when approximately 450 people paid admission to the grounds of the University to see all the sights prepared for them. On the campus twelve telescopes were set up, each with an observing programme for the evening. In the Science Building motion pictures on astronomical subjects were presented and the University's 5-inch refractor was in operation on the roof of the building. All through the evening, the public address system was used to explain the sights to be seen, and to publicize the planetarium project. This field night produced $75 after all expenses as a start on the fund.

All the members and friends of the Society were canvassed by personal contact and the response was very gratifying. Everyone showed a great enthusiasm for the project, and a total of $500 was raised in this way. When the presentation of the planetarium was made to the University an admission fee of 50 cents a person was charged and Convocation Hall was filled to capacity. This added $125 to our fund. The Mathematics Department contributed $75 from their budget and a total of $775 was now on the books. The balance was soon forthcoming.

The planetarium was presented to the University on November 5, 1949. Mr. Armand N. Spitz, inventor of the projector was present and was the speaker of the evening. Mr. Spitz was Director of Education for the Franklin Institute, Philadelphia, and a lecturer at the Fels Planetarium as well as director of the Spitz laboratories. Mr. Geo. E. Campbell acted as Chairman of the meeting and we had representatives on the platform from the Toronto, London and Guelph Centres as well as from Buffalo. The planetarium was presented by Mr. Truman M. Norton, President of the Hamilton Centre, and accepted by Dr. G. P. Gilmour, President of McMaster University. Dr. H. G. Thode, Principal of Hamilton College, where the planetarium was to be housed, spoke briefly saying that it would be "a definite asset to the University and an aid in teaching astro-

nomy here". We were fortunate in having Mr. Andrew Thomson, National President of the R.A.S.C., present; he gave the audience a brief history of the Society from its beginning in 1890. Mr. Ellsworth Jaegar introduced Mr. Spitz. Mr. Spitz took as his subject "The Value of Astronomy to the Layman". He touched briefly upon his reasons for developing the planetarium and also mentioned some of the problems he had encountered during its development. Following the formal part of the evening a colour sound motion picture "The Story of Palomar" was shown and Mr. Spitz gave several demonstrations of his projector.

The planetarium was first set up in a room in Hamilton Hall. Instead of a regulation dome for projection Professor McCallion and Mr. E. T. Clarke, Superintendent of Buildings and Grounds, McMaster University, designed a new type of roof. Rather than an immovable dome, a parachute was purchased and hung umbrella style from the ceiling when in use. The heavens could be projected on the silken cloth and when the planetarium was not in use, the parachute could be folded and hung on the side of the wall. In this manner the room could still be used as a classroom. This process was necessary since at that time McMaster University was very short of classroom space and a full classroom could not be stolen from regular use since it always had to be available for lectures during the day. This device of hanging a parachute from the ceiling also cut down the cost of the project considerably since the parachute was purchased for $20.

This parachute served as a dome for three years until 1952. Many demonstrations were given under this parachute but it had two serious difficulties. When a demonstration was to be given the chairs in the classroom had to be moved to the side of the room, the parachute lowered and screwed into umbrella shape and the chairs replaced under the dome for the demonstration. When the demonstration was completed the chairs had to be removed from the dome, the parachute folded and hung to the ceiling and the chairs replaced so that the classroom could be used the following day for lectures. This whole process involved the instructor in three and one half hours labour in order to present a one-hour planetarium demonstration. As the number of demonstrations increased it became apparent that something would have to be done to eliminate this particular difficulty.

The second difficulty was that the planetarium with this type of dome could be used at night only when darkness had fallen. This, of course, was a great handicap in teaching since it was not easy to assemble students in the evenings for classes.

Giving some considerable thought to this problem Professor McCallion

designed and erected a special planetarium dome in a classroom in Hamilton Hall. This dome was made of corrugated cardboard covering a wooden frame and placed on a circular wall of masonite. It was about 18 feet in diameter, 13 feet high and had a seating capacity of 60. This new dome was opened on September 26, 1952 when the Hamilton Centre had one of its annual Field Nights.

The construction of this dome saved considerable time since now an hour's demonstration required only an hour of the instructor's or demonstrator's time. In this way many more demonstrations could be presented and it was not unusual to have as many as three demonstrations in one evening. This dome continued in use until October 15, 1954 and although it eliminated one of the problems with the parachute dome it could still be used at night only.

On October 15, 1954, the new Physical Sciences Building for Hamilton College, McMaster University, was officially opened and this building contained a properly designed and completed planetarium dome. This new dome, also designed by Professor McCallion and Mr. E. T. Clarke, is 22 feet in diameter and is completely light-tight with central light control which allows the demonstrator to simulate any lighting conditions desired from murky dusk to bright daylight or deepest darkness. It reflects the stars just as if the viewer were looking at the sky itself.

Since this new dome is light-tight, lectures can now be held and demonstrations given at any time during the day. As a result of this, Public School, High School and Church groups frequently visit McMaster to view the stars as projected in the planetarium.

When this new dome was completed in the Physical Sciences Building the budget unfortunately ran out of money before seats could be purchased for the dome. At this time sufficient money, $1,500 in amount, was borrowed to purchase proper theatre type seats for the dome. Sixty such seats were purchased at a cost of $25 each. Then the opportunity was given to those people interested in the planetarium project to present a chair or chairs. A chair could be presented in honour of someone or in memory of someone or simply by someone. As a result of this campaign many of the chairs in the planetarium have been purchased for this purpose. A sufficient number of chairs has now been purchased to permit the installation of bronze plaques on these chairs. This will represent another milestone in the life of the McMaster planetarium as it celebrates its tenth anniversary in 1959.

As the planetarium prepares to celebrate its tenth anniversary it is interesting to note that it has been housed in three domes and has travelled on at least 25 occasions to surrounding towns for the presenta-

tion of planetarium demonstrations to the general public. In the ten-year period the planetarium has averaged 200 to 250 demonstrations per year which means that over the period of the last ten years somewhere in the neighbourhood of 150,000 people have had the opportunity of viewing the stars and hearing about the stars, people who probably would have had no contact whatsoever with astronomy.

As the number of demonstrations continues to increase it has become impossible for Professor McCallion to handle all of the demonstrations himself. Two members of the Hamilton Centre, The Reverend Norman Green and Mr. William J. Sled, have been assisting for the past year with these demonstrations.

The University has been grateful for the presentation of this planetarium since it has proven to be such a valuable teaching aid for astronomy classes and also has operated as a very excellent public relations instrument to make the University better known to the community.

It is fitting to mention that at the time the Hamilton Centre presented the Spitz planetarium to McMaster University the Centre moved its meetings to the campus. The Society had been holding its meetings in rented rooms in downtown Hamilton but the accommodations were far from satisfactory and the change in location started a new phase in the history of the Hamilton Centre. The membership increased and the attendance at meetings improved as the programme was broadened. Credit for a great deal of this success belongs to the University for its support in this project and the continued interest it has shown in the Hamilton Centre.

It is hoped that the experience of the Hamilton Centre will encourage other centres to establish planetaria in their respective cities to provide a means "of studying the stars without depending upon the stars".

THE HALIFAX PLANETARIUM

By M. W. Burke-Gaffney
Halifax Centre

In Halifax, in 1951, there was founded the Nova Scotia Astronomical Society, which, in January 1955, became the Halifax Centre of the R.A.S.C. Its first secretary was Mr. Donald Crowdis, Curator of the Nova Scotia Museum of Science. Mr. Crowdis's desire to bring the knowledge of astronomy to the youth of Nova Scotia was comparable to the zeal of Dr. Oskar von Miller, creator of the Deutsches Museum in Munich. As the Museum comes under the Department of Education, Mr. Crowdis could deem his desire something of a duty. His position, however, set limits to his expenditure. The budget of a Provincial Museum is tight. In 1955 a beginning was made by purchasing a Spitz Planetarium, Model A-I, console type, with twilight projector and projection pointer. After it had been installed and successfully operated, there were added the sun-moon-planet projector, the co-ordinates projector, the meridian projector, and the geocentric earth projector. The acquisition of the instrument, with its accessories, did not present a great problem. The challenging problem was the projection theatre. The solution of the theatre problem gave to the Halifax Planetarium an original dome and an original control console.

The Spitz Model A-I, when mounted on the console supplied by the Spitz Laboratories Inc., projects a horizon 6.5 feet from the ground. A dome of at least 20 feet in diameter is required to have the stars in good focus. Consequently, when so mounted, the Spitz Model A-I, should be installed in a room at least 16.5 feet high. The only room in the museum which Mr. Crowdis could allocate for the Planetarium was 14 feet high.

The museum was fortunate in having on its staff two members endowed with ability, energy and imagination—Mr. Len Carrigan and Mr. Bill Take. These two capable men designed and constructed a 20-foot dome, which comes to within four feet of the floor, and a new console, with the level for the star projector lowered.

In order to enter the projection theatre one does not have to be less than four feet tall. The original design of the dome permits the lowermost three feet of it to be raised—which it normally is. When the audience enters the room, the dome is seen to come to within seven feet of the floor. When the showing is about to commence, and the light-tight doors are closed, the bottom portion of the dome is lowered. It is only then

that the pictured Halifax sky-line comes into view. Members of the audience are admiring this, identifying roof-tops, towers and spires, when the light fades, darkness comes on, and stars begin to appear on the artificial celestial sphere. Showings, by appointment, began on February 6, 1956.

The dome is made of flannelette, of a fairly good grade. It is kept in shape by a frame made of one-quarter inch iron rods. The top of the frame is a hoop of about four feet diameter. From this hoop ribs run down to the seven-foot level. They run through flexible batten pockets which project from the back of the fabric. From the seven-foot level to the four-foot level there are no ribs, but only three concentric hoops, of which the lowermost is about 24.3 feet in diameter. When this portion of the dome is lowered, the hoops are supported by the fabric. The weight of the hoops contributes to keeping the fabric taut.

Neither the hoops nor the ribs come in contact with the fabric of the projection surface; they are about two inches behind it. Thus the surface is maintained smooth and unruffled. The Halifax sky-line, as depicted around the base of the dome, is an exact representation. A series of photographs were taken from the roof of the museum building. From the photographs the silhouette of the rooftops was drawn to scale, and then cut out in light-weight black felt, which was stitched on to the flannelette. All the work of seaming is excellent. The sphericity of the fabric was obtained by sewing together 24 segments. The sewing was done by Nova Scotia's best sailmaker, Mr. Randolph Stevens, of Lunenburg.

The frame of the dome is supported by a large, hidden, external framework of 2.5-inch steel pipe, resting on four legs. The whole contrivance could be dismantled in the course of a day, and could be transported and re-erected elsewhere. The console, on low castors, can be rolled in, or out, of the room in a minute. The room can be made ready for purposes other than a Planetarium in short time. In one corner of the room, half-hidden when the lower part of the dome is lowered, is a projection booth. The room is always half ready to be used as a movie theatre.

The museum in Halifax is centrally located. The use of its planetarium room as a meeting place for the Halifax Centre of the R.A.S.C. is very convenient. For this convenience, the Centre is indebted to Mr. Crowdis.

INTERNAL PRECISION OF THE DAILY RADIO FLUX OBSERVATIONS AT 10.7 CENTIMETRES

By A. E. Covington

Radio and Electrical Engineering Division, National Research Council, Ottawa, Ontario

Abstract

Analysis of 815 simultaneous readings of the 10.7-centimetre solar flux obtained from two independent radiometers shows that the relative basic probable error of a single reading is ±1% for a single radiometer. This must be increased to ±2%, or even ±3%, to include errors in the recording meters and in the variable transmission of the weatherproof dipole. The total relative probable error to be applied to the monthly means of the series of observations which commenced in 1947 has the same value.

The significance of solar energy as a source of energy for many processes in the earth's atmosphere and on the earth's surface, including that of life itself, has long been known. Within the last few years the growing interest in the sun as the predominant influence in the earth's physical environment has produced an increasing number of observations of this body. Perhaps this activity has come about through the recent appearance of instruments and techniques which have enabled new facets of the energy flow from sun to earth to be observed. Such is the discovery of the emission of radio waves, and we are now faced with the task of incorporating a new body of knowledge within a well established astronomical field. A basic factor in bringing this about is the realization that the emission of a radio wave of a particular length originates from a particular layer in the solar atmosphere; according to the proportion, the shorter the wave-length, the deeper the emitting layer. In particular, it has been found that the decimetre waves originate from the upper solar chromosphere, and the metric waves from the corona.

Intensive solar observations taken at the Goth Hill (Ottawa) Observatory of the Radio and Electrical Engineering Division of the National Research Council, have been conducted at a wave-length of 10.7 centimetres. At first the slowly varying component of the solar flux at this wave-length was shown to be correlated with the appearance of sun-spots, as indicated either by a sun-spot number or the area of sun-spots. However, later evidence pointed to a better correlation with the bright plage which has been well established as one of the more fundamental surface features. This region is seen only in the light of ionized hydrogen or calcium atoms and is also known to be the seat for the appearance of

bright elevated regions in the corona which are naturally seen only in the light emission from this region. At present the emission of radio waves associated with the appearance of a sun-spot region is regarded as originating from a coronal condensation, which is a relatively dense volume of the solar atmosphere existing over the spot. The variation in the intensity of emission from a single condensation will depend upon many factors such as its size, position on the disk, temperature, electron density, age, and time of existence in relation to the solar cycle. Since these properties are of great importance in solar physics, laws relating to the variations are being investigated both experimentally and theoretically at many observatories.

Attention has also been directed to the close correlation existing between the total flux of the ten-centimetre radio waves from the solar disk and the number of free electrons existing in the upper atmosphere of the earth at a level of 100 kilometres (the E region). This implies that the ten-centimetre radio flux, the ultra-violet, and the x-ray ionization are produced under the same conditions and originate from approximately the same region. The advantage of using the radio flux F for a solar index for the E-layer ionizing flux, I, in place of either a coronal index, C, or sun-spot area, A, is revealed in the series of scatter diagrams taken from the paper of Denisse and Kundu (1957), and here reproduced as figure 1. Intercomparing the scatter diagrams made with the three indices of solar activity, A, C, and F, the radio flux, F, gives the least scatter of points and the best approximation to a straight line passing through the origin. From this type of work it is obvious that significance is being placed upon the accuracy of measurement entering into the several variables. Any estimation of the errors in any of the parameters

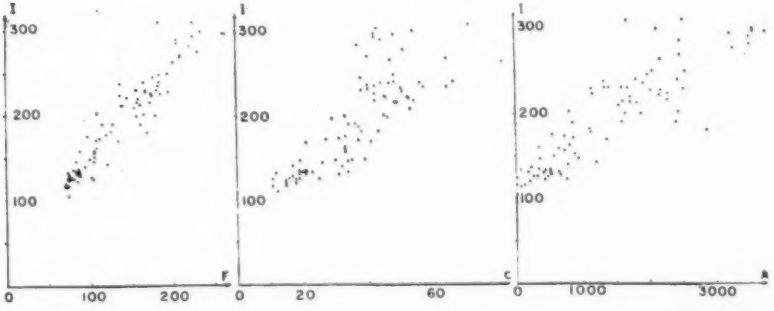


FIG. 1—Scatter diagrams of ionosphere ionizing flux, I, versus ten-centimetre radio flux, F, coronal intensity, C, and total area of sun-spots, A.

will be of great interest, and improved accuracy of observations will probably reveal hitherto unsuspected influences of natural origin.

Errors of Observation

In the case of the radio flux observations taken at Ottawa, some indication of the absolute and the relative errors has already been made (Medd and Covington 1958), but no systematic work has been reported on the variation of the relative errors over any extended period of time. To provide easy maintenance of electronic components, two complete radiometers have been constructed and their performance occasionally intercompared by using the same four-foot parabolic reflector and Esterline-Angus recorder. However, it has been only within the past two and a half years that the operating set and the stand-by have been used daily to give two readings which are averaged to provide a measure for the solar flux.

Any radiometer introduces small random variations into the calibration, and when repeated observations are made of a signal, different values of its strength are obtained. The average for a large number of results will give the best representation and will have some root-mean-square error, or standard deviation. The smaller this error, the more precisely the average is known. The measurement of this error by repeated observation of the solar signal is impractical since the signal itself undergoes small changes. However, when two similar radiometers have been operated at the same time to give two series of readings, the ratio of two nearly simultaneous readings eliminates the unknown true value of the solar flux, and variations in the ratio provide a measure of the errors introduced by the radiometers. Thus, a ratio of radiometer readings equal to unity indicates, on the average, identical performance of the two independent sets, and any deviation from unity represents the combined errors of the two radiometers. The observed variations of the readings must be regarded as percentage errors, and simple analysis of the propagation of errors shows that the standard deviation of the ratio of readings will be the same as the deviation in the sum of two readings. The daily flux, when obtained as the mean value of the two radiometer readings, will be half the sum of the two readings, and hence its deviation will be half that obtained from observing the ratio. Instead of using the standard deviation, s, to describe the precision of a reading, the probable error, p, is usually quoted, and is related to the standard deviation by the formula $p = 0.68\,s$. The probable error gives upper and lower limits to an observed value so that the indicated range of values includes one-half of the observations, the remaining ones being outside this range.

It may be readily found for the ratio (and also for the sum) from a plot of the number of times certain values occur within given small intervals. Since the mean is one-half of the sum, the probable error of the daily mean flux will be half of that for the ratio.

Observations

The ratio of the two daily flux readings has been calculated from the summer of 1956 until the end of 1958, and a group of 815 readings is available for study. The number of times a given ratio occurs in each interval of 0.01 or 1% is shown in the histograms of figure 2. All the values, with one exception, lie within an error interval of $\pm 9\%$, while a range of $\pm 1.3\%$ found from a more detailed examination of the data includes one-half of the total number of points. This latter interval gives the probable error of the ratio, and hence of the sum of the two readings; while one-half of this value, or $\pm 0.7\%$, is the probable error of the mean daily flux obtained by averaging the two independent readings.

The monthly means of the ratio have also been calculated for the same two and a half year period, and the frequency of occurrence of values in intervals of 0.5% is shown in figure 3 (a). In this case, the range of points

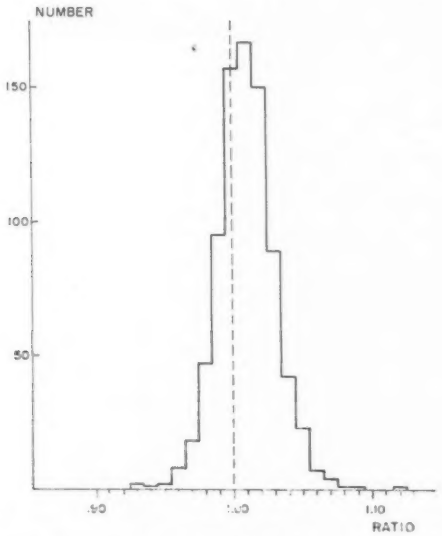


FIG. 2—Frequency of occurrence of ratio of two independent daily 10.7-cm. solar flux readings.

from low to high extends over the interval of ±1.8%, and a variation of ±0.9% includes one-half of the points. This gives a probable error of ±0.45% for the monthly means of the daily flux. This value is probably a poor estimate since the frequency curve does not have the smooth bell-

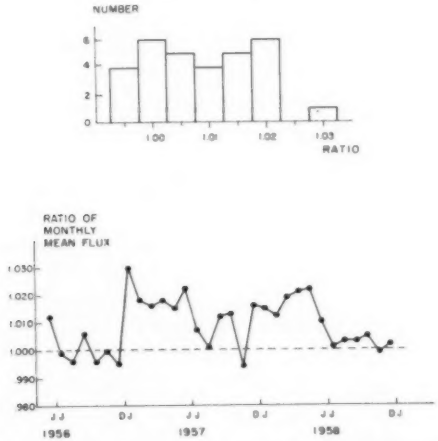


FIG. 3—(a) Frequency of occurrence of ratio of two independent daily 10.7-cm. solar flux readings averaged over one month.
(b) Serial plot of ratio of monthly means of ten-centimetre flux.

shape associated with the occurrence of random errors, and the value is much larger than that expected by taking the average of thirty truly random numbers. This failure of the daily ratio to exhibit a truly random pattern is readily evident in a serial order plot of these values, shown in figure 3 (b), as the sudden unexplained shift from one value to another after a period of several months. It will also be noticed in both figures 2 and 3 that one radiometer consistently gives a reading calculated to be 0.94% higher than the other.

In the calculation of a daily flux value, three steps are involved: the reading of levels on an Esterline-Angus strip chart, the interpolation or extrapolation from two fixed calibration levels to give the daily solar flux, and the application of a correction for the indirect radio emission from the earth. The reading errors are mainly determined by uncertainties introduced by receiver noise. The radiometers are calibrated from two fixed temperature points, one at the temperature of the sky, taken to be 8°K, and the other from the ambient temperature of a black box covering the antenna; consequently the effect of errors upon the final

value will depend upon the position of the third point, corresponding to the solar emission. During sun-spot minimum, this third point is between the two calibrating points so that a given error should have a minimum effect, while for sun-spot maximum this point is outside so that the same given error should have its maximum effect. This latter condition existed for the two and a half years under review, and a basic probable error of $\pm 0.7\%$ for the daily flux has been obtained for the averaged result of the two radiometers.

Although every effort has been made to maintain the same degree of performance throughout all past observations, it is now impossible to be absolutely certain that no serious error has crept in. This is particularly true for the early period, 1947–1949, when only one radiometer was available. The choice of an error to cover the day-to-day variations of the whole observing period is somewhat arbitrary, and in order to allow for other known sources of error the relative probable error should be increased to $\pm 2\%$, or even $\pm 3\%$. This error is compounded by taking the square-root of the sum of the square of individual errors. An error of $\pm 2\%$ includes the previously determined basic error of $\pm 0.7\%$ corrected to a value of $\pm 1\%$ since the results from a single radiometer are involved, together with an error of $\pm 1\%$ to take into account the constant difference which has been observed in at least two radiometers; an error of $\pm 1\%$ for the use of various Esterline-Angus recording meters, and $\pm 1\%$ for the varying losses in the weatherproof dipole cover. Since the error in the monthly mean values has been observed to be only slightly smaller in magnitude than the error for a daily reading, a similar accounting gives the relative probable error from month to month as also equal to $\pm 2\%$.

References

Denisse, J. F. and Kundu, M. R. 1957, *Compt. Rend. Acad. Sci.* (Paris), vol. 244, p. 45.

Medd, W. J. and Covington, A. E. 1958, *Proc. I. R. E.*, vol. 46, p. 112.

THE ARIZONA METEOR CRATER CONTROVERSY

By Matt Walton
Yale University, New Haven, Connecticut

For more than sixty years a curious controversy has gone on in the literature of astronomy and geology and in the offices of promoters and mining engineers. The controversy has to do with the size of the meteorite which produced the great impact crater near Winslow, Arizona, and how much of this mass remains buried beneath the crater as recoverable metal. Of course there was another controversy, as well, having to do with whether the crater was formed by meteorite impact or by some entirely terrestrial geologic process. This latter dispute has now been settled in favour of celestial origin to the satisfaction of every serious investigator, with one notable exception (Hager 1953).

However, the controversy about the mass of the impinging body and the amount buried beneath the crater still goes on unabated, so that within the past few years estimates of the mass have been published in the astronomical literature ranging from the order of 10,000 tons (Rinehart 1957) to the order of 10,000,000 tons (Rostoker 1953). The curious thing about the controversy is that all of the solutions to the problem of the size of the meteorite involve fundamental assumptions of one kind or another, and rarely are these assumptions fully stated or even recognized in the ensuing argument. Consequently some tens of thousands of years after the actual impact, this astronomical event is still generating heat. What I would like to offer here is a review and brief analysis of the assumptions on which some of the solutions rest.

Meteor Crater has been described in so much detail in the literature (Barringer 1905, Merrill 1908, Nininger 1956, Foster 1957) that I will present only the briefest summary of its salient features. The crater has an average diameter of 4,150 feet, a depth of 570 feet to the present floor, and highly disturbed and shattered rock extends to a depth of about a thousand feet below the present floor. Very imperfect records indicate that at least 20 tons of meteoritic iron fragments have been collected from the desert plain within a radius of several miles of the crater. The largest single fragment on record weighed 1,406 pounds, and there are many of more than 100 pounds. Sampling operations by Nininger (1956) and Rinehart (1957) have demonstrated that the top few inches of soil in an area of 100 sq. mi. around the crater contains about 10^4 tons of minute particles of nickel-iron, much of it in the form

of spherical droplets, presumably formed by the condensation of vaporized metal produced by the heat of impact (Nininger 1956). These tiny scattered particles thus represent the principal residue of the meteorite so far found, although there are other residues such as highly weathered ferruginous "shale balls" representing an unknown but possibly large additional mass of original material.

I think geologists would agree with Nininger that after several tens of thousands of years of erosion and weathering the minute droplets in the soil represent a residue from an original amount larger by perhaps a factor of ten. This factor is at best educated guesswork, but it is strongly corroborated by the fact that the metallic droplets now found in the soil are highly enriched in nickel compared to the composition of the parent meteorite as determined from the large fragments of unvaporized metal. This implies the dissipation of a much larger amount of vaporized metal than is now present in surviving soil particles, because in the condensation of a nickel-iron vapour the liquid phase is enriched in nickel in the early stages of condensation at high temperature and the later condensate is impoverished in nickel and richer in iron. Nickel imparts corrosion resistant properties to iron so it is reasonable to suppose that the iron-rich fraction has disappeared because it was more subject to destruction by weathering.

At any rate, Rinehart's assumption that the residue of metallic material now present in the soil of the desert represents most of the original mass of the meteorite (which assumption is necessary to bring his findings into agreement with his theory of crater formation) seems to a geologist used to considering the effects of mass-wasting processes to be far from realistic. It would thus seem reasonably well-established by direct observation that the meteorite was composed largely of metal with an average density of about 7 gm. cm.$^{-3}$ and a *minimum* mass on the order of about 10^5 tons.

To turn now to the problem of the size of the meteorite, it is evident that in the course of the controversy two separate, but related, problems have frequently been confused: (1) Evaluation of the mass-velocity function of the meteorite required to do the work needed to produce the crater; in other words, the problem of the size of the body that hit the ground. (2) Estimation of how much of the original body that hit the ground would remain in the ground as a residual buried mass after the conversion of its kinetic energy of motion into heat and work of various kinds.

There have been four ways of approaching the first problem, falling under two main headings:

(1) Finding a relationship between the dimensions of the crater and the dimensions of the meteorite.
   (a) By direct analogy with impact craters formed by bodies of known dimensions.
   (b) By theoretical and experimental analysis of the mechanics of impact crater formation.
(2) Finding a relationship between the work done in forming the crater and the kinetic energy of the meteorite.
   (a) By a detailed analysis of all the energy spent in heat and work by an in-falling meteorite.
   (b) By using an experimentally-derived scaling function to estimate the efficiency with which the total kinetic energy of the meteorite is converted into the work of forming a crater.

It would seem that these are all valid approaches to estimating a value for the mass-velocity function of the meteorite. It would also seem that they should give estimates in reasonable agreement if made on the basis of sound basic assumptions and primary data. So far the agreement among estimates made by these different approaches is far from reasonable.

The earliest attempts to estimate the size of the meteorite were based on comparison with a supposed mechanical analogy. G. K. Gilbert (1895) estimated the diameter of the meteorite by application of the ratio found experimentally between the diameters of balls of clay and the diameters of the craters they made when hurled at a clay target. He simply assumed tacitly, without critical analysis, that the mechanical analogy was simple and directly valid, and estimated the diameter of the meteorite as most likely about 1,500 feet. On this extraordinarily flimsy and naive foundation he erected a very pretentious argument purporting to show that the crater could not have been of meteorite impact origin. In fact he presented it to a distinguished audience as a model of the scientific method.

B. C. Tilghman (1905) used the tables prepared by military engineers for the reduction of stone masonry fortifications by heavy artillery solid shot. He concluded that the diameter of the meteorite must have been "considerably less than 450 feet" even if the velocity were not in excess of 1,800 ft./sec. and pointed out that it was extremely doubtful that the data would hold for impacts at "planetary velocity". Nevertheless he was repeatedly cited by later authors (cf. Merrill 1908) as having demonstrated that the meteorite was about 500 feet in diameter.

Öpik (1936) appears to have been the first to attempt a theoretical analysis of the mechanics of impact crater formation. His hydrodynamic analysis of the motion and resistance to deformation of a penetrating projectile and its target may be used to obtain independent approximations for the mass of the projectile in terms of either depth of penetration or crater volume (Rostoker 1953). His analysis indicated that once the velocity of the projectile is very much larger than the minimum velocity necessary to overcome the strength of the target, the depth of penetration is virtually independent of velocity, and the crater volume increases with only the first power of the velocity. Subsequent experimental work with ultra-high velocity steel jets produced by shaped explosive charges and aimed at steel targets seems to confirm Öpik's theory (Rostoker 1953), and numerical estimates by Rostoker based on Öpik's theory for the Arizona meteorite give a mass of 7.8×10^6 tons and an impact velocity of 20×10^5 cm./sec., on the same order as less detailed numerical approximations made by Öpik.

There are three aspects of Öpik's treatment that should be noted. First, the hydrodynamic theory is based on the fundamental assumption that the volume and density of the projectile remain constant throughout the process of crater formation, and also that the density of the target material remains constant. Second, no attempt is made to account for the dissipation of the total kinetic energy possessed by the projectile. Third, the phenomena of shock are not taken into account.

If a substantial amount of the kinetic energy is converted into heat by shock as the meteorite plunges into the earth, and if the temperature is raised to the point where a significant amount of the meteorite and the target material suddenly vaporize, then Öpik's analysis ceases to hold. Since Nininger (1953) has produced direct evidence for the vaporization of a substantial mass of meteorite material, and Gilvarry and Hill (1956) have shown that shock temperatures on the order of 10^5 to $10^{6\circ}$K. should be produced upon the impact of a large meteorite within the time it takes the body to penetrate a distance about equal to its own diameter, it is doubtful if Öpik's analysis would hold for craters produced by meteorites with impact velocities of more than 2 or 3 km./sec.

Consequently it is pertinent to inquire why Rostoker's (1953) experimental results with steel jets fired into steel targets at velocities within the lower range of meteorite impact are in reasonably good agreement with Öpik's theory. I would suggest that the answer probably lies in the assumptions made regarding the effects of the strength of the target material. It is clear that at sufficiently high impact velocities the effect of the strength of the material is virtually negligible in considering the

hydrodynamic behaviour. However, when the process enters into an explosive phase the strength of the target may become important in comparing the results of experiments using steel targets with meteorite impacts on the earth. In other words, a penetration pit in a steel target might well contain a very large vapour phase expansion without much additional deformation, the work of the explosion mainly being to eject the gas back out of the hole with great acceleration (a process observed every time a gun is fired). The same explosion contained in rock or earth might produce large deformation (a process observed in blasting). Consequently, if the experiments reported by Rostoker had an explosive phase the effects may not have been significant on a steel target, but one would have to predict that the same jets would produce craters that departed significantly from the hydrodynamic theory if directed at a target which accurately simulated the strength of rock at the scale of the experiment. Of course it is possible these experiments did not have sufficient shock energy dissipated as heat to produce a metallic vapour phase like that developed by meteorite impact.

One other detail of the calculations made by Öpik and Rostoker should be noted. The depth of penetration of the meteorite was assumed by them to be the depth to undisturbed rock beneath the crater as determined by drilling. The actual depth of penetration of the meteorite may have been much less than this, however, for the shock wave and compressive stress in the rock must have produced notable strain in the rock well beyond the maximum penetration. This would cut their estimates severely, quite apart from the questions raised with respect to the validity of the theory.

The crux of the problem involves an evaluation of the efficiency with which the kinetic energy of a falling meteorite is converted into the work of crater-making. If a large fraction of the energy was expended in blasting out the crater, then the mass need have been relatively small. If a large proportion of energy was expended in heating, pulverizing, and deforming the rock around the crater, producing a seismic disturbance which dissipated energy over a wide area, imparting a high velocity to a jet of vaporized material expelled back out of the crater, producing large atmospheric disturbances and blast effects above ground, and by radiant heat and light from the expelled vapour, then it may have been highly inefficient as a crater-producer and the mass may have been large.

A number of attempts have been made to evaluate the mass of the meteorite by evaluating in one way or another the efficiency with which its kinetic energy was converted into the work of crater-making. Estimates of this type have an inherently large uncertainty with respect to

the mass, because the kinetic energy is proportional to the square of the velocity, and so such estimates are very sensitive to any uncertainty in the assumed impact velocity. Estimates of velocity may vary by as much as a factor of 10 (from about 5×10^5 cm./sec. to about 50×10^5 cm./sec.) so an uncertainty as high as 100 fold is inherent. However, most students of the problem seem willing to allow a somewhat smaller range for the probable impact velocity, say from about 10×10^5 cm./sec. to about 40×10^5 cm./sec. Even so, the uncertainty is still 16 fold.

Evaluations which, in effect, are analyses of the crater-making efficiency of meteorite impact, take several forms. Perhaps the classic approach was that of F. R. Moulton. Moulton was commissioned about 1929 to make his estimate by a company formed to exploit the mass of meteorite metal which was presumed by them to be very large and to be buried beneath the crater. The work was never published in full, so far as I know, but a copy of his report is said to be held in the library of the Museum of Northern Arizona in Flagstaff. According to Nininger's (1956) account of the contents of this report, Moulton assumed that the impinging mass was in the form of a compact, disk-shaped swarm of discrete small bodies, an assumption he apparently felt was necessary to explain the large diameter of the crater and at the same time keep the mass commensurate with the amount of energy to be accounted for. He assumed the velocity of entry into the atmosphere was between about 10×10^5 cm./sec. and 25×10^5 cm./sec., and then he attempted to account in detail for the dissipation of the energy of such a mass in heat and various types of work. From this analysis he deduced what proportion of the energy was devoted to crater-making, and from the estimated quantity of work represented by the existing crater he estimated the total kinetic energy of the meteorite. Depending on the values assigned to the velocity and to some of the other doubtful parameters, the corresponding values for the mass of the meteorite ranged from about 5×10^4 tons to 3×10^6 tons.

Other investigators have attempted to short-circuit some of the uncertainties and difficulties inherent in Moulton's method by finding some mechanical analogue or experiment on which to base an estimate of the crater-making efficiency of meteorite impact. Wylie (1943), for example, compared the chemical energies expended in large man-made explosions with the size of the craters formed by the explosions. He used for comparison military mine explosions and large nitroglycerine explosions. He then assumed, without much critical analysis, that the kinetic energy of meteorite impact is converted into the work of crater-making with the same over-all efficiency as the chemical energy of a nitrogly-

cerine blasting charge. As LaPaz (1943) was quick to point out, this is not an assumption that can be accepted prima facie. Chemical explosives vary widely in effect depending on the type of ground, the way the charge is set, and the detonating characteristics of the charge. The precise characteristics and crater-making efficiency of a meteorite impact explosion are uncertain, even though there is good reason to assume that the impact would produce an explosion comparable to the detonation of a high-energy explosion at the surface. Moreover, Wylie made a simple, empirical extrapolation from the relationship of crater size to explosion energy for a few chemical explosions which were small in comparison with the Arizona crater. His conclusion was that the mass would be about 8.5×10^3 tons for an impact velocity of about 15×10^5 cm./sec.

Rinehart (1950) made a similar estimate using an empirical relation between crater volume and explosion energy also based on relatively small experimental explosions. He made a simple linear extrapolation to the Arizona crater and concluded that it was produced by an explosion with an energy of about 10^{22} ergs. This corresponds to a meteorite of 12.5×10^3 tons with an impact velocity of 15×10^5 cm./sec.

Recently Hill and Gilvarry (1956) have made a more sophisticated analysis of the scale relations between crater dimensions and explosion energy. Their results are controlled by the empirical relationship established by Baldwin (1949) between crater diameter and crater depth over a range of crater size extending from those produced by relatively small terrestrial explosions to lunar craters many miles in diameter. Their scaling functions lead to results that depart by an order of magnitude from the uncontrolled extrapolations by Wylie and Rinehart.

Hill and Gilvarry obtain an explosion energy of 2×10^{23} ergs for the Arizona crater. This corresponds to the kinetic energy of a meteorite of about 4×10^5 tons at a velocity of 10×10^5 cm./sec., which is a reasonable lower value for the impact velocity of a large meteorite. At 20×10^5 cm./sec. the mass would be only about 9×10^4 tons. These values compare closely with the estimates given earlier in this paper of the probable tonnage of meteorite material that was disseminated over the ground surface around the crater in the form of small particles, presumably produced by the condensation of vaporized nickel-iron. From the agreement of these two completely independent arguments one would conclude that the Arizona crater might well have been formed by a meteorite with a mass of the order of 10^5 tons to a few times 10^5 tons which was largely vaporized on impact as its kinetic energy was dissipated in a crater-making explosion.

Recent experiments with underground nuclear explosions have no doubt yielded additional data for scaling explosion energy to crater-making effects. I have not attempted to find out if these data corroborate the analysis of Hill and Gilvarry as I presume the information is classified. However the very good agreement between the theory and the estimates obtained by sampling the site is encouraging. In terms of size, a meteorite with a mass of one hundred thousand metric tons and a density of about 7 gm./cc. would have a volume of about 1.4×10^{10} cc., corresponding to a sphere with a diameter of about 30 metres or roughly 95 feet. The diameter would not be likely to be much less than this nor more than about fifty per cent. larger.

The foregoing pages have outlined the problem of how large a mass was required to make the meteor crater. Estimates have varied widely depending on the assumptions made explicitly or implicitly concerning the mechanics and efficiency of the crater-making process and the velocity of impact. However, to answer the question of the size of the meteorite that struck the earth provides no direct or simple answer to the problem of how large a residual mass might be buried beneath the surface. The first investigators such as Gilbert, Barringer, Tilghman, etc., made the simple assumption that the meteorite merely displaced the ground to form the crater and buried itself, more or less intact, beneath the surface. It was only when later workers, starting with Merrill but principally with Moulton, began seriously to consider the dynamics of the situation that it became evident that this would be impossible except at improbably low impact velocities.

At impact velocities within the probable range, the kinetic energy of the body becomes very large. A valid theory must give an adequate account of the dissipation of this energy. The low estimates of the mass made by Wylie and Rinehart were based implicitly on relatively high estimates of efficiency and low estimates of the energy required to produce the crater. On the other hand the very large estimates of mass by Öpik and Rostoker account for only about ten per cent. of the kinetic energy that such a mass would possess at the impact velocity they estimated. In this case it becomes necessary to assume that the crater-making efficiency of the impact is very low and that most of the energy is dissipated in other ways. In any case we have an obvious dilemma. Either the crater-making efficiency of the process is high and the impinging body has a correspondingly small initial mass which is dissipated in the explosion. Or else the crater-making efficiency of the process is low and the large excess of kinetic energy must be dissipated in other ways, the most probable being the evolution of enormous amounts of heat, which would

vaporize and destroy the mass. What is needed is an adequate theory of the exact process of energy transformation involved in the impact.

The only detailed analysis based on modern physical theory that I know of has been presented by Gilvarry and Hill (1956), using a hydrodynamic and quantum statistical mechanical approach. They show that within the probable range of impact velocities for a large meteorite a shock wave is set up in the body which traverses the body in about the time it takes the body to penetrate approximately half its diameter into the ground. Behind this shock wave all interatomic bonds are broken and it passes into a degenerate gas phase with a temperature between 10^5 and $10^{6\circ}$K. The energy stored in this tremendously hot, highly compressed gas is then released as a violent explosion in which the metallic vapour phase expands and is dissipated.

This analysis indicates therefore that the mechanics of meteorite impact approximate in crater-making effect the mechanics of very large, rapidly detonated explosions. The validity of the scaling functions of Hill and Gilvarry for relating crater dimensions to the kinetic energy of the moving body rests on this theory. The obvious consequence of this theory is that it predicts there will not be any sizeable residual mass buried beneath the impact crater.

In fact the problem now is to account for the presence around the crater of a good many tons of unvaporized meteoritic iron fragments, rather than to explain the absence of a residual mass. Nininger (1956) has shown that there are not only some iron fragments with primary textures and compositions that indicate they come from separate masses, but that there is a very pronounced secondary variation in the textures of the fragments that make up the bulk of the irons recovered in the area. Fragments collected some distance from the crater show excellent Widmanstätten figures (a crystalline texture revealed by etching polished surfaces of the metal), but those collected on or near the crater rim show the effects of annealing by intense heat which obliterates the Widmanstätten pattern. No meteorite fragments have been found within the crater, and drilling tests beneath the rim and floor of the crater have produced only finely divided nickeliferous material in highly pulverized rock, although there has been much conjecture and controversy as to whether some of the difficulties experienced in exploratory drilling were caused by encounters with large metal fragments in which drills were blunted or lost without ever actually producing any definite metal cuttings.

The finely divided material can probably be accounted for by the condensation of vapour shot into the pulverized rock during the impact

explosion, back-fall of a rain of condensed metal and rock dust after the explosion, etc. However it becomes necessary to assume that the fragments of meteoritic iron around the crater, which show a range of temperature effects extending from just below melting to below the temperature of rapid annealing, were peeled off and hurled away from the mass ahead of the shock wave in some manner that is hard precisely to visualize, since initially every particle of the falling body contained the same kinetic energy per unit mass. It also seems necessary to assume that the fall was a composite one consisting of a main body with satellitic masses of variant composition.

Until the presence of a certain amount of unvaporized, even relatively unheated, meteorite fragments in addition to the residue of condensed vapour can be adequately accounted for by a detailed theory, the problem of the Arizona meteor crater cannot be regarded as completely solved. One of the conclusions that emerges from this review is that the absence of residual meteorite fragments in the vicinity of a crater is no argument against its origin by meteorite impact. Large meteorites are apt to be totally vaporized if they strike as a single compact mass. If the meteorite were of stony rather than metallic composition, the silicate condensation products would probably not survive weathering very long and would be difficult to recognize or collect in the soil.

References

Baldwin, R. B. 1949, "The Face of the Moon", Univ. Chicago Press.

Barringer, D. M. 1905, *Acad. Nat. Sci. Phila. Proc.*, vol. 57, p. 861.

Foster, Geo. E. 1957, "The Barringer (Arizona) Meteorite Crater". Privately published.

Gilbert, G. K. 1895, *Geol. Soc. Wash.*, Presidential Address, p. 3.

Gilvarry, J. J. and Hill, J. E. 1956, *Ap. J.*, vol. 124, p. 610.

Hager, D. 1953, *Am. Assoc. Petroleum Geol. Bull.*, vol. 37, p. 821.

Hill, J. E. and Gilvarry, J. J. 1956, *Jour. Geophys. Res.*, vol. 61, p. 501.

LaPaz, L. 1943, *Pop. Ast.*, vol. 51, p. 339.

Merrill, Geo. P. 1908, *Smith. Inst. Misc. Coll. Quarterly*, vol. 50, p. 461, Pub. no. 1783.

Nininger, H. H. 1956, "Arizona's Meteorite Crater, Past–Present–Future", World Press, Denver.

Öpik, E. 1936, *Acta et Comm. Univ. Tartu.* A, v. 30 p. 1.

Rinehart, J. S. 1950, *Pop. Ast.*, vol. 58, p. 458; 1957, *Sky and Telescope*, vol. 16, p. 366.

Rostoker, N. 1953, *Meteoritics*, vol. 1, p. 11.

Tilghman, B. C. 1905, *Acad. Nat. Sci. Phila. Proc.*, vol. 57, p. 887.

Wylie, C. C. 1953, *Pop. Ast.*, vol. 51, pp. 97, 158.

CANADIAN SCIENTISTS REPORT—XVII

SHOCKS, SHELLS AND SUPERGIANTS

By Anne B. Underhill

Dominion Astrophysical Observatory, Victoria, B.C.

The spectrophotometric studies completed during the last two decades agree in indicating that many details of the spectra of shell stars and of early-type supergiants may be explained in terms of a body of low density gas which is moving. This moving gas may be considered to form an outer atmosphere of lesser or greater extent depending on the type of star. The motions of the gas in the outer atmosphere are quite considerable in some cases, and may amount to 100 km./sec. or more. Generally, however, the differential motions are of the order of 10 to 50 km./sec.

The question arises as to how the gas of the outer atmosphere obtained the kinetic energy stored in these motions. A somewhat similar problem exists when one considers the β Cephei variables. Odgers and Kushwaha (1959) have shown that the decay of a shock wave under isothermal conditions may account for the observed phenomena for BW Vulpeculae. Their ideas are relevant also to the case of shell stars and early-type supergiants. It is possible that in shell stars and supergiants we are observing the results of a decay of a field of shocks. That is, kinetic energy is transferred to the observable gas layers by shocks originating further inside the star. When a spectrogram is obtained, we get an instantaneous picture of the field of velocity (line-of-sight component) in the outer atmosphere. This picture changes from time to time because the field of shocks feeding the energy into the observable atmospheric layers changes in an irregular manner. In the case of BW Vulpeculae, because of the lesser extent and higher density of the atmosphere, one observes the decay of one shock at a time with perhaps a small overlap on the following shock. As the atmosphere becomes more extended and transparent, with a lower density, the time for a shock to decay will increase, and it is possible to observe the overlapping effects of several shocks. The arguments given by Odgers and Kushwaha justifying the assumption of isothermal conditions remain valid in the case of early-type supergiants and shell stars, thus the decay time of a shock in the outer atmospheres of these stars will depend chiefly upon the density

of the gas in the neighbourhood of the shock front. The lower the density, the longer the shock front lasts as a recognizable disturbance that can transmit kinetic energy to the surrounding gas.

At present we shall not inquire what interior conditions could cause the sudden instabilities that appear as shocks, but rather review the observed spectral changes in shell stars and supergiants and show how they may be interpreted to support the hypothesis of shocks decaying. The unified point of view that results may make easier the search for the initiating cause of the disturbances.

The spectrum of an early-type supergiant consists chiefly of rather blunt, steep-sided absorption lines which show little or no Stark broadening. Frequently a weak emission feature occurs at Hα and at λ5876 of He I. The N III multiplet at λ4640 and C III λ5696 may also appear in emission in the O9 supergiants.

The following general conclusions may be drawn.

1. The atmospheres of the early-type supergiants are of relatively moderate extent, for the emission lines are weak and dilution effects are not conspicuous.

2. The density is fairly low. For instance, curve of growth analysis by Buscombe (1951; α Cyg), Unsöld (1944; 18 B-type stars), Voigt (1952; 55 Cyg), Aller (1956a, 1956b; ϵ C Ma, 55 Cyg) yield a pressure of the order of 100 bars and T_{exc} running from 10,000° for α Cygni, A2 Ia, to 31,000° for α Camelopardalis, O9 I. The electron density is of the order of 10^{13} electrons/cm^3. For a pure hydrogen atmosphere completely ionized this corresponds to a density of 1.7×10^{-11} g./cm^3.

3. Hydrogen is effectively completely ionized throughout the observable atmosphere of an early-type supergiant, the fraction of neutral atoms being less than 10^{-4}.

4. Profiles of the absorption lines are quite wide, corresponding to motions of the stellar atmosphere (macroscopic turbulence) of 20 to 40 km./sec. (Goldberg 1939, Underhill 1948, Voigt 1952, Struve and Huang 1953, Aller 1956a, b). Struve and Huang found that it is impossible to distinguish observationally between a rotational velocity of the order of 20 to 40 km./sec. and a true macroscopic velocity distribution in the atmosphere with a root-mean-square velocity of this order. This conclusion is also supported by the observations of Slettebak (1956). The effects of electron scattering (Münch 1948), and of absorption in a stationary, spherical atmosphere (Underhill 1948) both tend to produce shallow wings on otherwise sharp absorption lines and to make the core less deep. In point of fact, the profiles of the absorption lines in supergiants of earliest spectral type cannot be readily interpreted in an unam-

biguous manner. The steep-sided blunt profiles of the spectral lines of the very luminous A- and late B-type supergiants are plausibly interpreted in terms of macroscopic motion in the part of the outer atmosphere before the stellar disk. Rotation may play a role in some of the less extremely luminous stars such as 67 Ophiuchi and ρ Leonis.

5. The average velocity of atoms in early-type supergiant atmospheres that is deduced from curve of growth studies is of the order of 5 to 8 km./sec. This velocity (often called a microscopic turbulent velocity) is considerably less than the root-mean-square value of the velocity field suggested by the widths of the lines.

6. Irregular radial velocity changes of small amplitude are known to occur for many supergiants (cf. Abt 1957). These changes suggest slow outward motions of the exterior layers of these stars. To this evidence of expansion may be added the P Cygni character of the Hα profile in all very luminous stars.

7. In spite of these minor variations, the spectrum of an early-type supergiant remains essentially unchanged for 50 years or more. Therefore the atmospheres ot these stars must be in a quasi-stable state.

The spectroscopic changes occurring during a period of activity of a shell star are more striking than those of a supergiant, yet basically they exhibit many of the same characteristics and may be explained in terms of the same phenomena. The shell spectrum is the record of the interaction between a field of high temperature radiation and a low density gas which may be moving and which has an electron temperature (the temperature defined in times of the motions of the electrons) of the order of 10,000° or higher.

The properties of a shell around a B-type star and the spectroscopic phenomena associated with this shell are summarized below. The specific example in mind is the shell star 48 Librae which has been extensively observed by Merrill and Sanford (1944), by Merrill (1953), and by Underhill (1954, 1957). Other shell stars show somewhat different spectroscopic details, but they conform to the general pattern that is outlined here. The time scale of the development is usually the most conspicuous point of difference. Some stars remain quiescent for 20 to 50 years; others show more or less cyclic variations in periods of 5 to 10 years. Details evident on high-dispersion spectra of 21 shell stars are summarized by Merrill and Lowen (1953). A number of investigations of individual stars by various authors may be found in the literature.

Properties of shells around B-type stars:

1. The atmosphere is very extensive, and it can be subdivided into two more or less distinct parts: (i) an inner region with a density of the order

of that of a supergiant atmosphere, and (ii) an outer low density halo which is transparent except in the frequencies of strong absorption lines. The inner part of the shell can be considered to be an equatorial bulge of the rapidly rotating B star. The radius of the inner shell is usually of the order of 2 to 3 stellar radii (from dilution effects and from the shapes of the profiles in the case of rotationally broadened shell lines). The radius of the outer shell is about 10 to 15 stellar radii as determined from the strengths of the emission lines. In the outer shell, the electron density may be of the order of 10^{12} to 10^{11} electrons/cm^3. The inner shell produces absorption spectral features similar in many respects to those of supergiants. The outer shell may be observed only in spectral features typical of low density gas at an electron temperature of 10,000° or so. Because of the extent of the outer atmosphere, dilution effects are strong.

2. Since the absorption lines of a shell spectrum strengthen and fade from time to time, it is clear that the density of material in the inner shell where most of these lines are formed varies secularly. There is no conclusive evidence that the electron temperature changes by a significant amount as the inner shell forms or dissipates. Strengthening and fading of the H and Fe II emission lines and of the H and Fe II absorption cores is an index of the density and spatial changes of the outer shell.

3. The profiles of the absorption lines formed by an active shell often appear composite. In the case of Pleione and of ζ Tauri (Underhill 1949, 1951) the profiles of the lines which arise from the inner shell are dish-shaped as though broadened by rotation. In the spectrum of 48 Librae, the profiles of the lines formed in the inner shell do not appear dish-shaped. Rather they are steep-sided and blunt. They may be considered to be broadened either by a very slow rotation or by turbulence with an average velocity of the order of 30 to 40 km./sec. Relatively sharp, narrow absorption lines from the gas of the outer shell are superposed upon these basic profiles. The sharp profiles may be displaced with respect to the underlying lines if the part of the outer atmosphere lying in front of the stellar disk has a relative velocity in the line of sight with respect to the inner shell. The asymmetries shown by some shell lines as the radial velocity changes secularly (Merrill and Lowen 1953) probably are due to radial velocity shifts. It is significant that not all lines of a shell spectrum show these asymmetries equally. Those lines which are strengthened in a diluted radiation field are usually most asymmetric.

4. Although the shapes and the displacements of the absorption lines formed by an active shell may change significantly, real changes in the emission features are not so large. The shape of the wings of the Hα emission feature in 48 Librae has not changed during the period 1950 to

1958, although large V/R changes have occurred. The changes in the apparent relative strengths of the violet (V) and red (R) components of the emission feature are caused by a strong absorption core shifting across the stationary emission feature. This simple explanation of the well-known V/R changes in shell stars was suggested by Merrill and Sanford (1944) to explain their observations of 48 Librae, and it is confirmed by detailed study of the Hα profile of 48 Librae in recent years. It is to be surmised that if the self-absorption which appears as the absorption core were not so strong, the emission profile would appear quite like a Wolf-Rayet emission band. Since the shape of the emission line as a whole does not appear to change, so far as can be determined from measurements in the wings, the distribution of velocity in the gases contributing to the emission feature, that is, in the whole outer shell, remains constant. The absorption core changes position as the average radial velocity of the gases in front of the disk of the star changes. It should be noted that Hα has a very strong absorption core in B-type shell stars, and that therefore the Doppler shift of this absorption line reflects the radial velocity of only the outermost layers of gas. The wings of the Hα emission in 48 Librae extend to $\pm$600 km./sec. The extreme width is close to $\pm$1000 km./sec. for the shell of ζ Tauri. The Hα emission is very wide in all B-type stars with strong shell spectra. The extent of the Hα emission wings is too great to be accounted for by rotation, unless one is willing to postulate a rotation that increases in linear speed as one goes outward.

5. When a shell is active, different layers of gas may have different radial velocities. The shell does not have a uniform outward or inward motion. The most direct evidence of the real spread in velocity that exists is the phenomenon called by Merrill and Sanford (1944) the "Balmer Progression". When the inner shell of 48 Librae is moving outward with a velocity of 50 km./sec. or so, Merrill and Sanford noted that the radial velocity given by the first members of the Balmer series was less than that derived from the high members such as H25 or H30. Since the higher members of the series are much weaker intrinsically than the first members of the series, the average point in the shell where the high members are formed will lie deeper in the shell (closer to the stellar surface) than the effective point of formation of absorption Hα or Hβ. The observed difference in radial velocity between members of the Balmer series can only mean that there is a decided velocity gradient in the shell. When there is a definite Balmer progression, differences in radial velocity are also observed between lines from different ions. The most usual case that is observed is that the inner layers of a shell are moving outward more rapidly than the outer layers. Merrill, however, has

observed a few cases of a reversed Balmer progression. If the outward velocity is given to the gas by acoustic disturbances (shocks), then it is logical that the inner regions should receive the greatest outward component because these parts of the shell are closest to the origin of the shocks. By the time a shock has been transmitted to the outer shell it will have decayed somewhat, and therefore it cannot impart such a large kinetic energy to the gas as it did when it first appeared. In addition, the gravitational attraction of the central mass of the star will also tend to decelerate any outward motions of the atmosphere.

6. The spectral changes of shell stars frequently take place in periods of the order of 5 to 10 years. Large changes have not often been observed to occur in a matter of hours or a few days. The spectacular outbreak of γ Cassiopeiae in 1932 (for a descriptive summary see Edwards 1956) is one of the few cases when changes have been observed to occur rapidly. The changes in the spectrum of 48 Librae occur at a more leisurely rate. Some shell spectra, for instance that of 1 Delphini, remain unchanged for years.

It is perhaps significant to place the early-type stars known to have extended atmospheres in the following order:

Object	Atmospheric velocities
supergiants	10 km./sec.
shell stars	100
Wolf-Rayet stars	1000

This is also the order of extent of atmosphere. The supergiants have the smallest atmospheres; the Wolf-Rayet stars have the most extensive atmospheres.

We are faced with a barrage of questions. What is the origin of these velocities? Is it shocks? If so, what causes the shocks to appear at observable depths? Are these velocities occasioned by a randomly occurring imbalance between radiation pressure and the acceleration of gravity? The imbalance could be caused by the opacity of some region changing suddenly as a result of ionization changes. If so, what causes the ionization changes? Hydrogen is effectively completely ionized throughout the observable outer layers of all these stars, so it is unlikely that the velocities arise as a result of a classical hydrogen convection zone. Furthermore it seems unlikely that enough energy storage could occur through the second ionization of helium in observable layers to produce large velocities in a He II convection zone. We should also like to ask how is hydrostatic equilibrium affected by rotation and are magnetohydrodynamic effects important. These questions are easy to ask; they are not easy to answer.

In recent years it has become apparent that gas is streaming at speeds of 500 km./sec. or more from the outermost parts of the solar corona in a so-called "solar wind". Parker (1958a, 1958b) has discussed the evidence for this phenomenon, and has given a theoretical discussion to show that the rapid streaming of low density gas is an inevitable result of the hydrodynamical situation. Perhaps the solar wind is related in its origin to the large outward motions which have been postulated in the past to explain the profiles of the emission lines of Wolf-Rayet stars and which may also account for the width of the Hα emission in shell stars. The density of the solar corona is several orders of magnitude less than that estimated for shells and for the atmospheres of Wolf-Rayet stars, but the solar corona is like a shell or a Wolf-Rayet atmosphere in that it is a plasma of highly ionized gas.

Although the motions of the gases in the outer atmospheres of shell stars and of supergiants produce striking spectroscopic effects, the kinetic energy that these motions represent is a small fraction of the total energy radiated by the star per second. Thus the mechanism that transfers kinetic energy to the gases does not have to be efficient or uniform in its working. One of the most interesting facets of the situation is the fact that the overall field of velocities as made visible by the shape of the emission lines changes little if at all over long periods of time even though the velocity of the gases projected against the disk of the star (visible in the shell absorption lines) may change quite rapidly by 10 to 100 km./sec.

References

Abt, H. A. 1957, *Ap. J.*, vol. 126, p. 138.

Aller, L. H. 1956a, *Ap. J.*, vol. 123, p. 117; 1956b, *Ap. J.*, vol. 123, p. 133.

Buscombe, W. 1951, *Ap. J.*, vol. 114, p. 73.

Edwards, D. L. 1956, "*Vistas in Astronomy*" (ed: Beer, Pergamon Press, London, and New York), vol. 2, p. 1470.

Goldberg, L. 1939, *Ap. J.*, vol. 89, p. 623.

Merrill, P. W. and Sanford, R. F. 1944, *Ap. J.*, vol. 100, p. 14.

Merrill, P. W. 1953, *Ap. J.*, vol. 117, p. 7.

Merrill, P. W. and Lowen, A. L. 1953, *Ap. J.*, vol. 118, p. 18.

Münch, G. 1948, *Ap. J.*, vol. 108, p. 116.

Odgers, G. J. and Kushwaha, R. S. 1959, *P. Dom. Ap. O.*, vol. 11, no. 6, (in press).

Parker, E. N. 1958a, *Ap. J.*, vol. 128, p. 664; 1958b, *Ap. J.*, vol. 128, p. 677.

Slettebak, A. 1956, *Ap. J.*, vol. 124, p. 173.

Struve, O. and Huang, S. S. 1953, *Ap. J.*, vol. 118, p. 463.

Underhill, A. B. 1948a, *Ap. J.*, vol. 107, p. 247; 1948b, *Ap. J.*, vol. 107, p. 349; 1949, *Ap. J.*, vol. 110, p. 166; 1951, *P. Dom. Ap. O.*, vol. 9, p. 139; 1954, *P. Dom. Ap. O.*, vol. 9, p. 363; 1957, *P. A. S. P.*, vol. 69, p. 401.

Unsöld, A. 1944, *Zs. f. Ap.*, vol. 23, p. 100.

Voigt, H. 1952, *Zs. f. Ap.*, vol. 31, p. 48.

NOTES

Andrew McKellar: The President of the R.A.S.C.

Andrew McKellar was born in Vancouver, B.C., and received his honour B.A. degree in physics from the University of British Columbia in 1930. He proceeded to graduate study in the Department of Physics of the University of California, receiving the Ph.D. degree in 1933. Following this he was awarded a Post-Doctoral Fellowship by N.R.C. (U.S.). In 1935 Dr. McKellar was appointed to the staff of the Dominion

Andrew McKellar, President, R.A.S.C.

Astrophysical Observatory and has been continuously on the staff since that time. He now holds the position of Assistant Director. During the War, Dr. McKellar served with the Royal Canadian Navy and in 1947 was awarded the M.B.E.

Dr. McKellar is a member of Commissions 9, 15 and 29 of the International Astronomical Union. He was President of Commission 15, responsible for studies of comets, from 1948 to 1952 and has been active on the Commission responsible for studies of molecular band spectra. He was elected a fellow of the Royal Society of Canada in 1942. He was President of the Astronomical Society of the Pacific from 1956 to 1958.

Dr. McKellar's astronomical work has been in the interpretation of stellar spectra with particular emphasis on studies of molecular spectra of stars and comets. In these fields he is a recognized authority and, as such, has been asked to take leading parts in international symposia and in the preparation of authoritative articles.

Obituary: Rev. W. G. Colgrove

Rev. W. G. Colgrove, M.A., B.D., a valued member of the London Centre of the R.A.S.C., passed away in London on October 26, 1958, in his 87th year. Born in London, Mr. Colgrove received his education at the University of Western Ontario, McGill and the Boston Theological Seminary. He served a church in Worcester, Mass., and later was the minister of several churches in south-western Ontario.

For many years he was an active member of the London Centre, receiving the Chant Medal for 1942. He contributed much to the popularizing of astronomy through talks, articles and booklets. Following his retirement Mr. Colgrove devoted much time at the Hume Cronyn Memorial Observatory of the University of Western Ontario designing and constructing excellent instruments for teaching astronomy. As unofficial curator of the Observatory he gave demonstrations and lectures to many groups. It was through his active interest and initiative that the Observatory was successful in securing the Dresden Meteorite, a treasured possession.

Surviving are two sons, Dr. Gordon of Coppercliff, and Rogers (Pete) of Toronto; one daughter, Mrs. Ada Kay of Toronto; three grandchildren; three brothers, Charles E., Toronto, Robert J., Los Angeles and Mark G., Calgary; and one sister, Mrs. Clara May Symmonds, London.

H. R. Kingston

METEOR NEWS

By Peter M. Millman

National Research Council, Ottawa, Ontario

A New General Book on Meteors

One of the most important books published in recent years on the subject of meteors is a volume entitled "Meteoric Phenomena in the Earth's Atmosphere" by I. S. Astapowitsch, published December 1958, by the State Publishing House of Physical-Mathematical Literature, Moscow B-71, U.S.S.R. The order number is 3211, price 23 roubles, 50 kopecks, about $6.00 at the standard rate of international exchange.

My correspondence with Dr. Astapowitsch on meteoric matters dates back to about 1934 and reference to back numbers of the Journal in the pre-war years will reveal quite a number of items about meteor astronomy in the Soviet Union which resulted from this correspondence. It was not however until the summer of 1958, when I was in Moscow on the occasion of the 10th General Assembly of the I. A. U., that I had the pleasure of meeting Dr. Astapowitsch. We had a number of long talks, although the language barrier prevented us from communicating our ideas as fully as we would have liked. One of the most valuable circumstances of an international scientific meeting is the opportunity it gives one for meeting those from other countries who are co-workers in a subject. This is especially treasured when it follows many years of correspondence.

Dr. Astapowitsch was originally located in Moscow at the Astronomical Institute, but more recently he has been Chief of the Astrophysical Laboratory at Ashkabad, capital of the Turkmen Soviet Socialist Republic. This State is situated along the southern border of the U.S.S.R. next to Iran and Afghanistan. In my last letter from Dr. Astapowitsch I learn that he has just moved to the Odessa Astronomical Observatory, Odessa, a town in the Ukrainian Soviet Socialist Republic on the shores of the Black Sea.

The volume referred to above is entirely in the Russian language but it is not difficult to understand the significance of the numerous tables and illustrations. The text consists of 640 pages and includes 285 illustrations that cover a very wide range. Of particular interest is the large

number of meteor photographs reproduced. To my knowledge many of these have not appeared before in print.

Naturally I have not been able to read the complete work as yet, but it may be useful to indicate the subjects covered. After a general summary and an historical introduction there are chapters on the eye as an observing instrument, and on the effects of the conditions of observation.

FIGURE 1—A view of the Astrophysical Laboratory at Park Keshi, Ashkabad, at the edge of the desert in the Kopet-Dag foothills. Some 20 meteor spectra have been photographed here in the course of the programme of meteor photography.

The various methods of observing meteors are next described in turn, the visual, photographic and radio techniques being covered in a chapter each. The following chapters deal with meteor numbers, radiants, heights, velocities, orbits, luminosities, and spectra, respectively. After this the reader's attention is called to a discussion of the thermal radiation, dimensions and form, rotation and fragmentation of meteoric bodies.

The subjects of aeroballistics, meteor decelerations, physical meteor theory, and meteor masses and ionization are dealt with in five chapters. There are interesting chapters on the gaseous trains and dust trains left

by fireballs and also discussions of electro-magnetic and seismic phenomena associated with the fall of large meteors and meteorites. Meteorite showers and meteor craters, and the total quantity of meteoric material falling on the earth's surface, are subjects treated in the closing chapters.

Not the least valuable feature of the book is a bibliography of over 1000 references to scientific papers on meteors.

As will be realized from the title, and the above summary of contents, this book does not deal specifically with the complex of meteor orbits and their relation to the orbits of other objects in the solar system. But for any discussion of meteors in our atmosphere this volume should be considered a standard reference work and Dr. Astapowitsch is to be heartily congratulated on its publication.

A Lyrid Meteor Cluster

The following observation of interest has been received from Mr. W. A. Feibelman, who has been co-operating on both the auroral and meteor I. G. Y. programmes.

For about one hour, from 21:35 E.S.T. to 22:35 on April 21/22 the sky was very clear. At 21:46 of that night a very startling sight was seen: A cluster of meteors moved at extremely high speed from the region of Ursa Major to Gemini. There were at least 4 separate meteors distinguished, the brightest of them about + 1.5^m. The other three were about of magnitude 2, and an equal number of fainter ones may have been present. These meteors were seen simultaneously and covered an area not more than ½ of a degree, giving the appearance of a luminous ball. The path ended between Castor and Pollux without a terminal burst. No train was seen, but the bright moon may have interfered.

Although the cluster moved through part of the field of view of one camera and a spectrograph no trace was found on the films. In view of the high speed and low brightness this does not seem surprising.

At 22:05:00 a yellow Lyrid of mag. –1 was seen exactly along the same path. Both cameras had just been closed to advance the film to the next position and thus no record was obtained. At 20:35 thin clouds covered the sky and remained for the next few days.

W. A. Feibelman,
1063 Findley Drive,
Pittsburgh 21, Pa.

REVIEW OF PUBLICATIONS

Two Histories of Astronomy

And There Was Light (The Discovery of the Universe) by Rudolf Thiell. Pages xv plus 415, with 54 photographs and 73 line drawings; 6½ × 9½ in. New York, Alfred A. Knopf, and Toronto, McClelland Stewart Ltd., 1957. Price $7.50.

Discovery of the Universe by Gerard de Vaucouleurs; translated by B. Pagel. Pages 328, with 20 photographs and 35 line drawings; 5¾ × 9 in. London, Faber and Faber Ltd., 1956. Price 30*s*.

Here are two books, both outlining the history of astronomy, published within a few months of each other, the title of one being the same as the subtitle of the other. Yet they are very different. Both are excellent, but they will appeal to different readers. The one is popular, episodic, and journalistic in style, the other is thorough, and reasonably technical.

The author of *And There Was Light* is Rudolf Thiell, a German writer with a life-long interest in astronomy. In his book he has traced the story of astronomy from its beginning ("Mystic Childhood") to its present state ("Beginning of a Sixth Book"). About half of the book is devoted to pre-Newtonian astronomy in which the lives of the great astronomers are presented with a good deal of colourful anecdote and thrill of achievement. After Newton there is a gradual shift of emphasis from personalities to topics, but to the very end of the book each successive discovery is presented with a sense of excitement and scientific triumph. The treatment is definitely of the science-leaps-ahead variety in the best *Reader's Digest* tradition. This is not meant as condemnation of the book, but as a warning that the non-scientific reader may be deceived by the over-simplification of ideas and the uncritical attitude towards data which characterizes this type of science writing. With reservations along these lines, the book is recommended as good, nourishing, and slightly intoxicating fare in astronomy for the general reader who wants an easy-to-read, up-to-date account of the subject.

As to the accuracy of Mr. Thiell's book, it is difficult to make a categorical statement because of its avowed intention (according to the jacket "blurb") to be "non-technical and free of scientific jargon". The reviewer found few strictly inaccurate statements, but he found passages

which were woolly simply because the non-technical language is inadequate to cope with the ideas attempted. This is particularly noticeable in the sections on such difficult topics as the origin of the solar system, the evolution of stars and galaxies and cosmology. Perhaps it would be fair to say that one gains from a reading of the book acceptable impressions rather than thorough understanding.

And There Was Light is beautifully produced and illustrated with many helpful sketches and a magnificent set of 40 plates of telescopes and celestial objects. In the appendix there are some tables of astronomical data (inaccuracies and errors are noted in the table of the solar system) and a chronological table of astronomical discoveries. The book was translated from the German by Richard and Clara Wilson to whom much of the credit must presumably be due for the colourful style of writing.

The other book, *Discovery of the Universe*, is by Gerard de Vaucouleurs, a well-known French astronomer who was for some time on the staff of Mount Stromlo Observatory in Australia and who is now at Harvard. He is known to astronomers for his work on external galaxies and for two excellent books on Mars.

Dr. de Vaucouleurs' book is more frankly a history of astronomy than is Mr. Thiell's. It has numbered sections and references. It is distinctly technical in its language and in its method of presentation. In respect to modern astronomy it is more thorough and more methodical. It is more difficult to read, but it is by no means beyond the understanding of the general reader.

Dr. de Vaucouleurs explains in his Foreword that his book differs in two respects from other recent histories: he has de-emphasized the biographical material in favour of the evolution of ideas, and he has minimized the space devoted to the obsolete speculations of the Ancients. Thus within forty pages of text he has covered astronomy up to and including Newton; the remaining 250 pages are devoted to a development of modern astronomy which is essentially chronological but at the same time topical. This is not easy to do without awkward jumpings back and forth, but Dr. de Vaucouleurs has done it with a good deal of skill, maintaining the narration without unduly interrupting the treatment of topics. His cross-references are very helpful to a reader wishing to follow a topic through.

There is no better way to form a good understanding and appreciation of modern astronomy than to follow its historical development, sometimes making a great leap with the genius of a Newton, sometimes plodding along with the patience of a Flamsteed, sometimes threading through the maze

with the insight of a Baade. The guide who leads one along the tortuous route must himself be a skillful teacher, a competent critic and, above all, an unbiased observer of the overall scene. In the reviewer's opinion Dr. de Vaucouleurs is not always unbiased. There are repeated references to Australian astronomy and to Mount Stromlo Observatory (which is good), but there is only one reference to a Canadian astronomer and no reference to any Canadian observatory (which is bad). Some topics also get short shrift. For example, stellar radial velocities are almost completely dismissed after mention of the work of Huggins in 1868 and of Vogel in 1887. The sun's motion, galactic rotation and galactic structure are discussed a number of times without a word said about the role played in these studies by radial-velocity measures. As to double stars, if a reader missed twelve words on page 115, he could read the entire book without realizing that the whole subject of stellar masses and all its implications hinge upon double star studies. Perhaps it is this same cavalier attitude towards double stars which accounts for the fact that one can look in vain for any account of recent work on eclipsing systems or any reference to the astronomers best known in this field. There are other sins of omission and underemphasis, notably in respect to topics which have been most active during the past decade such as evolution of the solar system and nucleogenesis in stellar interiors.

These criticisms are not to say that *Discovery of the Universe* is a poor history. In the main it is excellent. It is an astronomer's history of astronomy, and it is the first adequate successor in English to the well-known Berry's *Short History of Astronomy*. It deserves a place in every astronomical library.

J. F. HEARD

Combination of Observations by W. M. Smart. Pages 253; 5¾ × 8¾ in. Cambridge, University Press, 1958. Price $6.00.

The fruits of scientific experiments are almost invariably of a numerical nature and are affected by experimental error. In the interpretation of his observations the scientist must in some way combine them, in simple cases by taking an average, or perhaps by curve-fitting. The experimental errors are propagated in these processes. This book presents the theoretical background and the rules for combining numerical results wisely.

In the opening chapter statistical distributions, both discrete and continuous, are introduced as a basis for the treatment of the theory of errors; moments in general, and the normal law and its integrals, are

treated in detail. After a survey of the various kinds of errors met with in physical measurements, the discussion in the second chapter is concentrated on accidental errors. The idea that the mean of n observations of a variate is an estimate of the true value is developed on a postulational basis as well as in terms of the principle of least squares, and the classical justification of the normal law of errors is presented. Similar material is treated in the third chapter on the basis of probability theory. Various formulas for measures of precision based on the normal law are developed in Chapters 4 and 5.

When the measured quantity is a function of two or more unknowns, and the number of equations of condition exceeds the number of unknowns, the best value of the unknowns, together with estimates of their precisions can be obtained by the method of least squares; this forms the subject of Chapter 6, the longest in the book.

If the aim of the investigation is to obtain a functional representation of the distribution of a variable, procedures in Chapter 7 will be found useful, and the correction of these distributions for the effects of grouping and of accidental errors are discussed in Chapter 8. The last chapter deals with correlation and other attributes of bivariate and trivariate distributions. Among the tables in the Appendix is one of the error function.

The book has the merit of bringing together in logical consort a variety of mathematical procedures which have shown their usefulness in the analysis of observations. The author has achieved a nice balance between writing a book of rules and presenting an exposition of principles of analysis. On the one hand the formulas are brought together and summarized from time to time. On the other, the mathematical development is clearly and carefully carried out along formal and classical lines. The level of analysis is that of a senior undergraduate in an Honours course, but there are plenty of numerical examples which often are used to elucidate the preceding discussion. Symbols are clear and consistent and only a few misprints were detected.

The principal shortcoming of the book is that it does not show how sound judgments of the reliability of numerical results can be formed. What is the proper interpretation of μ/n, the standard error of the mean? The student may be led to the conclusion that the true value of a variate differs from the arithmetic mean of a sample of N by either $+\ \mu/n$ or $-\ \mu/n$, the principal uncertainty apart from the sign being in the precision with which μ can be estimated from the sample. The experimenter who has gone to the trouble of calculating the standard errors of the unknowns in a least-square solution should be in a position to say more,

when they are small, than that "considerable confidence" can be placed in the results, and what can he say if they are not small? Tests of significance, about which there is a great body of useful knowledge, are not considered. Again, how well does an assumed distribution law fit the residuals in a set of observations? Objective criteria of goodness-of-fit, which would enable us to go beyond a statement that the agreement is "remarkably good on the whole", are not presented.

Other criticisms of a more minor nature relate to the statement of the principle of least squares and the diagrams. With regard to the latter, the leptokurtic curves drawn to represent the normal law would make Gauss turn over in his grave.

As a compendium of the rules of procedure in the combination of observations, together with the principles and the analysis on which they are based, and for a discussion of some topics which are brought together from scattered sources, this book can be recommended to all scientists.

DONALD A. MACRAE

The Spectrum of Beta Lyrae by J. Sahade, S.-S. Huang, O. Struve and V. Zebergs, in Transactions of the American Philosophical Society, New Series, vol. 49, pt. 1, 1959. Philadelphia, The American Philosophical Society, Price $2.00.

Beta Lyrae is one of the most remarkable stars in the sky. Known since 1784 as an eclipsing binary with a period of about 13 days, its spectrum demonstrates such unusual variety of emission and absorption features and so many variations that it has been the subject of many investigations. One could take the attitude that it is not worth-while to expend so much effort on a star which is so completely atypical, but Dr. Struve has for many years taken an exactly opposite view. He and his collaborators believe that Beta Lyrae, by the very fact of its uniqueness, represents a binary system caught in a "moment" of rapid change which may be a brief but important phase in the evolution of many close binary systems. They attribute the measurable change in period to actual loss of mass, and they have estimated that the present stage of evolution of Beta Lyrae may last not more than 50,000 years.

As a general rule stellar evolution is such a slow process that we may study it only by statistical means, that is to say, by observing the characteristics of many stars and inferring that different classes of stars represent different phases of stellar evolution. In Beta Lyrae, according

to Dr. Struve's belief, we can actually watch a star undergoing change, and he has repeatedly re-emphasized that we must not miss the opportunity to build up a mass of observational data not only to compare with data from a century ago, but for future astronomers to compare with their observations made centuries hence.

It is particularly for this reason no doubt that Dr. Struve and his collaborators obtained in 1955 a long series of very fine spectrograms of Beta Lyrae with the Mount Wilson Coudé spectrograph. In this publication they have presented beautiful reproductions of 195 of these spectrograms together with an extremely careful study of the radial-velocity curves and their interpretations of these results in terms of the orbital motions, rotational motions and motions of gas streams. One can venture to say that this study of Beta Lyrae will remain a classic for many generations of astronomers to come and will continue to shed light on the remarkable behaviour of this unique star.

J. F. HEARD

NOTES FROM OBSERVATORIES

DAVID DUNLAP OBSERVATORY, RICHMOND HILL, ONTARIO

A grant has been received from the National Research Council for the construction of a grating spectrograph for the 74-inch telescope to succeed the one-prism spectrograph which has been in use since 1935. Recent developments in gratings and in mirror optics for spectographs now make possible the design of spectrographs which are several times more efficient than prism spectrographs and which at the same time offer a greater choice of dispersions.

The research work in radio astronomy is continuing under a further grant from the National Research Council. New research projects being undertaken this summer are the investigation of the properties of long Yagi antennas for use as elements of a high resolution array and the development of a parametric amplifier for low-noise applications in radio astronomy. The Department of Electrical Engineering has installed an antenna pattern recorder at the Observatory. Dr. Gart Westerhout of the Leiden Observatory visited the Observatory for a few days in April. Mr. David Hogg, a graduate student here who recently received his M.Sc. from Queen's University, visited the National Radio Observatory at Green Bank, W. Va., for ten days in May. The radio astronomy group is participating with the National Research Council in plans for a national radio observatory in Eastern Canada. The site which has been chosen in Algonquin Provincial Park is reasonably accessible and at the same time less subject to interfering radio signals than any other possible site yet investigated in North America.

To accommodate the increasing number of visitors to the Observatory, a new paved parking lot for 60 cars has been constructed at the south side of the Administration Building, and the old parking area in front of the building has been converted to a landscaped area with a circular drive and a paved walk to the Dome.

Dr. Sidney van den Bergh, who joined the staff a year ago, has made good use of the Palomar Observatory-National Geographic Society Sky Atlas which was acquired by the Observatory as a gift from the Atkinson Charitable Foundation. Dr. van den Bergh has designed a means of classifying galaxies as to intrinsic luminosity from the appearance of the nebular images on the Sky Atlas prints. This method may lead to important new ideas on the distribution of the galaxies.

Dr. Helen Hogg has completed a long article on star clusters which forms part of the 53rd volume of the monumental *Handbuch der Physik* being published by Springer of Berlin. This particular volume is the fourth on the subject of Astrophysics and is entitled "Stellar Systems".

Dr. Leonard Searle is spending a period of three summer months at Mount Wilson and Palomar Observatories where he expects to obtain observational material for a study of relative abundances of the elements in stars of different dynamical characteristics.

Mr. Gustav Bakos, who is completing his Ph.D. thesis on the subject of the colour-magnitude diagram for visual binary stars, has accepted a position as astronomer at the Smithsonian Astrophysical Observatory in Cambridge, Mass., where he will be concerned with the satellite tracking programme.

Mr. Pierre Demarque, also completing a Ph.D. thesis on the subject of stellar structure, has accepted a position on the teaching staff in the Department of Physics and Astronomy at Louisiana State University.

Mr. Wallace Russell has spent the past year as an assistant in the Department of Astronomy and at the Observatory. He has accepted a teaching position in the Mathematics Department of East York Collegiate.

Among those attending the American Astronomical Society meeting in Rochester in April were Dr. Hogg, Dr. Searle, Dr. van den Bergh and the writer.

The following students are employed at the Observatory for the summer: Miss Kulli Milles, Messrs. Robert Lawson, Philip Locke, Helge Mairo, Stewart McCormick, Duncan McNeil and David Sher.

JOHN F. HEARD

HUME CRONYN MEMORIAL OBSERVATORY, LONDON, ONTARIO

During 1958 several items of equipment were added at the observatory. A twelve-inch reflector was installed alongside the refractor and on the same mounting. The effective focal length at the Cassegrain focus is 206 inches. A photoelectric photometer will be permanently mounted at this position. This photometer is under construction and is nearing completion. Provisions are being made for the measurement of polarization, with the emphasis on convenience of operation for a single observer. A one-degree objective prism was obtained for the Schmidt telescope.

Photoelectric observations of peculiar A stars were continued during the summer and fall. Preliminary results have been obtained for several

of these stars and indicate that two are constant over several months while there is evidence for the variability of two others.

Experiments on coincidence phenomena in coherent light beams were carried out for comparison with the physical theory of the Brown and Twiss intensity interferometer. The dependence of the coincidence rate on resolving time, polarization, line width and coherence were studied. An enhancement of the rate over that expected for purely random coincidences was detected and the results are being compared with theoretical predictions.

An astronomy option, leading to the degree of Bachelor of Arts, has been introduced in the Honours Mathematics and Astronomy course.

Visitors at the observatory have included Dr. John Heard, Dr. Helen Sawyer Hogg and Dr. Harold Urey.

WILLIAM WEHLAU

VARIABLE STAR NOTES

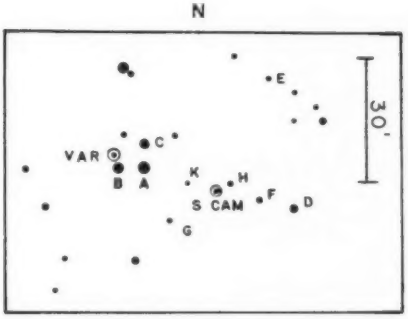
By Margaret W. Mayall

The American Association of Variable Star Observers, Cambridge, Mass.

NEW VARIABLE STAR IN CAMELOPARDALIS, $5^h\ 35.4^m + 68°\ 49'$ (1900).

Early in 1949 an A.A.V.S.O. member, Robert Greenley, called attention to a star not far from the variable 053068 S Camelopardalis, which he thought showed variability. He was asked to keep a close watch on it to confirm its variation. David Rosebrugh and several other observers volunteered to help out. Sufficient material has been accumulated during the last 10 years to permit a detailed study of the variable.

The star is not in the *Bonner Durchmusterung*, and the position given above is an approximate one. Figure 1 shows the location of the variable, and visual magnitude of the S Camelopardalis comparison stars.



STAR	VIS MAG
A	8.1
B	8.4
C	9.0
D	9.5
E	10.0
F	10.2
G	10.7
H	11.2
K	11.6

The variable appears to be very red, and is probably of late spectral class, but it is too faint to classify on any available plates at Harvard Observatory.

Individual observations show very large scatter, in all probability due in large part to the colour of the variable, but rapid fluctuations are not ruled out. Figure 2 is a plot of the 10-day mean values of the observations from 1949–1959. The extremely large scatter during the first two years is probably due to what we might call "psychological variation". It is usually found in the first observations of a newly discovered variable, when the observer subconsciously estimates the star either brighter around maximum, or fainter at minimum, than it actually is.

A preliminary mean curve was formed and the observed dates of maxima and minima were determined. Figure 3 is the revised mean curve computed from the elements:

$$\text{Maximum} = \text{J.D. } 2{,}433{,}745 + 366^d \times \text{Epoch}$$

Mean range of brightness is 10.0 to 10.6. The table gives the observed dates and magnitudes of the maxima and minima.

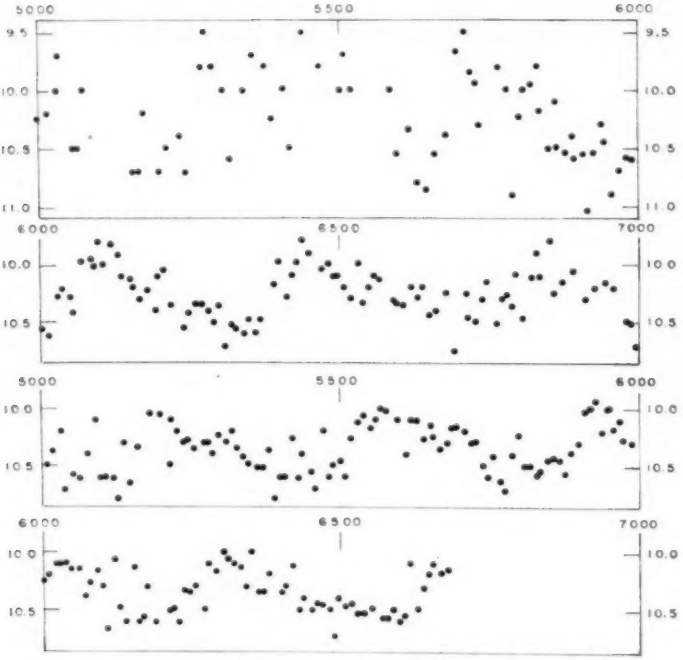


FIGURE 2. 053568 — CAM

10-DAY MEAN CURVE 1949 — 1959

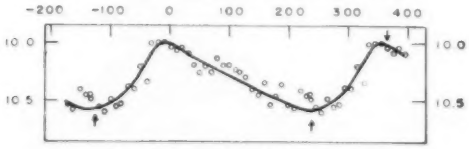


FIGURE 3. 053568 — CAM

MEAN LIGHT CURVE

OBSERVED MAXIMA (M) AND MINIMA (m)

Epoch	M	diff.	mag.	m	diff.	mag.	M-m
0	2433745	355	9.9	2433618	365	10.6	127
1	4100	342	9.9	3983	352	10.7	117
2	4442	398	9.9	4335	350	10.6	107
3	4840	356	10.0	4685	385	10.5	155
4	5196	364	10.1	5070	362	10.6	126
5	5560	380	10.1	5432	368	10.6	128
6	5940	370	10.0	5800	385	10.6	120
7	6310		10.1	6185	367	10.6	125
8				6552		10.5	
Mean		366			367		128

Miscellaneous notes on some U Geminorum-type variables.

060547 *SS Aurigae*. The following maxima have been observed since Dec. 1957: 6239, 11.7?; 6304, 10.8; 6427, 11.1?; 6538, 10.6; and 6629, 10.8.

061115 *CZ Orionis*. A faint variable, followed by only a few observers. The observed light curve is very weak, and many maxima depend on a single observation. Dates of maxima and observed magnitudes during 1958 are: 6628?, 11.9; 6652?, 12.3; 6269?, 12.4; 6286?, 12.8; 6301?, 12.5; 6312?, 12.6; 6498, 12.1; 6528?, 12.0; 6587, 11.8.

074922 *U Geminorum*. A narrow maximum was observed on 6529, magnitude 9.5, assigned number 369. It is assumed that the wide maximum, number 368, was missed by A.A.V.S.O. observers. Maximum number 370, a wide one, was well observed on 6650, magnitude 9.2.

094512 *X Leonis*. Intervals between maxima of this star average about 22 days. In the following list, a questioned date depends on one observation: 6226?, 12.9; 6250, 12.2; 6271, 12.1; 6288, 12.3; 6311, 12.5; 6330, 12.1; 6521?, 12.2; 6572?, 12.1; 6593, 11.8.

184137 *AY Lyrae*. Another very faint U Geminorum-type star for which we need careful observations. Some of the best observed maxima during the last year are: 6311, 13.7; 6362, 14.2; 6376, 12.0; 6426, 13.8; and 6484, 13.4.

184826 *CY Lyrae*. A maximum was observed by Thomas Cragg on 6370, mag. 14.5.

195109 *UU Aquilae*. Three maxima were observed: 6410, 11.5; 6453, 12.1; and 6506, 11.6.

203501 *AE Aquarii*. The most useful observations of this star are those made in runs of not more than a few minutes apart. It varies almost continuously, and all observations must be well timed. Some of the best observed flareups are on the following dates: 6382, 6386, 6387, 6392, 6397, 6408, 6417, 6425, 6426, 6428, 6431, 6432, 6435, 6451, 6452, 6455, 6458, 6480, 6482, 6486, 6490, 6492, 6511, 6515, 6517, and 6523.

220912 *RU Pegasi*. This is one of the most difficult variables to observe. It has a close 12.5 magnitude companion, and requires very careful observing to assure an estimate of the brightness of the correct star. During the year there was one well-observed maximum, 6507, 10.8 mag; and a probable one at about 6314, magnitude 11.

Minimum of 054319 SU Tauri, an R Coronae Borealis-type variable. SU Tauri, which has been at maximum since July 1956, has finally decreased about 4 magnitudes. It is between magnitudes 9 and 10 at maximum. The first of March 1959 it began to fade, and by the first of May it was about 13.5 magnitude.

Observations received during March and April 1959: A total of 7,541 observations was received: 3,842 from 58 observers in March, and 3,699 from 59 observers in April.

Observers	March		April		Observers	March		April	
	Var.	Ests.	Var.	Ests.		Var.	Ests.	Var.	Ests.
Adams, R. M.	70	142	87	153	Halbach, E. A.	..	..	14	14
Ahnert, P.	12	142	..	..	Halvorson, D. O.	7	9	..	..
Albrecht, W. B.	..	..	4	4	Hartmann, F.	112	118	128	141
Allin, R.	37	147	33	100	Hull, A.	..	..	3	3
Anderson, C. E.	109	181	64	106	Hunter, T.	..	..	1	1
Anderson, E.	4	4	9	9	Hurless, C.	..	..	6	6
Anderson, R. E.	11	12	..	..	James, R. A.	..	..	6	6
Bales, R. M.	2	2	5	7	Judd, D.	..	..	22	25
Barrera, S.	4	14	..	..	Kelly, F. J.	10	22	15	21
Bell, B. H.	42	42	..	..	Lacchini, G. B.	12	25	11	24
Berg, R.	..	..	4	4	Lorusso, D.	1	1	..	..
Bicknell, R. H.	14	35	..	..	Lowder, W. M.	11	11	..	..
Bohannon, B.	4	16	1	2	Melville, E. C.	..	..	6	6
Breckinridge, J.	5	5	..	..	Miller, W. A.	6	6	14	17
Byrd, W.	..	..	8	11	Montague, A. C.	17	19	25	34
Carlisle, J. H.	..	..	6	12	Morgan, F. P.	23	49	24	50
Carpenter, C. B.	3	3	..	..	Nestler, J.	10	89	..	..
Celis, L.	3	19	..	..	Nightingale, H. C.	2	8	3	10
Cragg, T. A.	79	85	255	333	Oravec, E. G.	166	284	189	415
Darsenius, G. O.	12	23	24	79	Parker, P. O.	41	50	84	100
Debono, I. P.	..	..	3	3	Pearcy, R. E.	2	2	..	..
de Kock, R. P.	113	466	127	584	Peltier, L. C.	16	58	26	96
de la Vega, R.	8	100	..	..	Peters, P.	8	11	3	3
Diedrich, DeL.	2	3	2	3	Rizzo, P. V.	16	26	20	36
Diedrich, G.	6	12	7	12	Robinson, L. J.	1	1	7	25
Dudley, R. R.	11	44	11	30	Rosalsky, R.	..	..	1	1
Engelkemeir, D.	11	25	9	32	Rosebrugh, D. W.	16	93	12	71
Erpenstein, O. M.	12	31	11	11	Rosenfield, C. C.	..	..	1	1
Estremadoyro, V. A.	..	..	10	10	Rosenfield, D. A.	..	..	1	8
Fallon, F. W.	2	2	..	..	Salce, H.	5	16	..	..
Fernald, C. F.	172	354	166	374	Silveira, W. M.	2	2	..	..
Fletcher, D. M.	5	5	8	8	Sloan, M. A.	..	..	1	2
Ford, C. B.	155	156	98	100	Solomon, L.	6	10	5	5
Fuller, K.	39	45	28	31	Taboada, D.	125	221	109	178
Garland, G.	17	146	..	..	Traynor, F.	5	14	6	11
Godfrey, N. B.	..	..	16	16	Valdez, M.	58	354	49	197
Gomochak, J.	..	..	4	9	Wallerstein, G.	..	..	1	5
Greenley, R. M.	8	8	11	15	Wend, R. E.	2	2	4	4
Grossenbacher, R. W.	8	9	..	..	Yamada, T.	34	63	45	125

A.A.V.S.O. Nova Search Report (From George Diedrich, Chairman): Observations of Nova Search Areas were made by the following 17 observers for a total of 324 area-nights during the first two months in 1959. Each name is followed by the number of observations made in January and then February, 1959: Harley S. Decker–4, 0; Frank J. DeKinder–11, 12; DeLorne Diedrich–5, 8; George Diedrich –14, 10; C. L. Drolet–0, 10; Kenneth Fuller–5, 5; Geoffrey Gaherty, Jr.–6, 9; William L. Isherwood, Jr.–28, 18; Howard C. Nightingale–8, 15; David L. Sands –2, 4; F. Traynor–13, 10; Robert Venor–11, 7; George Wedge–12, 14; Karl A. Wells–6, 0; James F. Wesling–4, 10; Isabel K. Williamson–4, 10; K. Zorgo–21, 26.

The results of all the above observations were negative. We are pleased to report an increase in the list of observers, including two this month from Australia. Welcome aboard. Let us all "Keep Looking".

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